Comments on Superluminal Photon Tunneling

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Abstract

Various expressions for transit times in frustrated total internal reflection are analysed. The incompatibility of evanescent-wave propagation with Einstein causality is established.

The phenomenon of frustrated total internal reflection illustrated in Figure 1 has been the subject of a considerable amount of research (see [1] and references therein).

The explicit expression for the transit time in frustrated total internal reflection has been obtained by Ghatak and Banerjee [2]. This expression infered from the stationary phase analysis has the form

$$\tau = \frac{2}{(k_{1z}^2 + K^2)k_{1z}K}\left(\frac{k_1}{v_1}K^2 + \frac{k_2}{v_2}k_{1z}^2\right) \qquad (1)$$

for $Kd \gg 1$. Here

$k_1 = \frac{\omega}{c}n_1$, $k_2 = \frac{\omega}{c}n_2$, $k_{1x} = k_1 sin\theta_i$, $k_{1z} = k_1 cos\theta_i$, $K = \sqrt{k_{1x}^2 - k_2^2}$,

k_1 and k_2 are wavenumbers in regions I and II, K is the evanescent-wave wavenumber , v_1 and v_2 are group velocities in regions I and II, n_1 and n_2 are refractive indexes, θ_i is the incidence angle, ω is the frequency of the incoming wave, d is the barrier width.

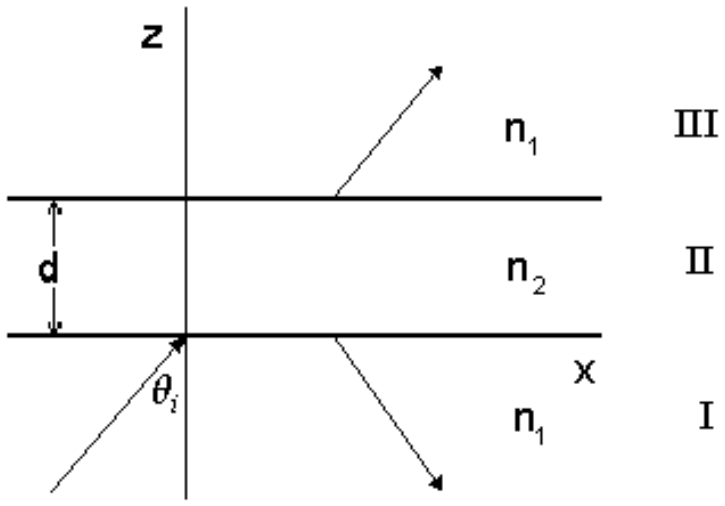

Figure 1

Another expression for the transit time has been recently proposed by Jakiel, Olkhovsky and Recami [3]. This expression infered from the analogy between photon and nonrelativistic-particle tunneling has the form

$$\tau = \frac{2}{cK} \tag{2}$$

for $Kd \gg 1$.

Note that formula (1) is valid for all available values of parameters (n_1, θ_i). The formula (2) is valid only in the vicinity of

the singular point ($n_1{=}\sqrt{2},\ \theta_i{=}\ \frac{\pi}{4}$) because

$$\frac{2}{cK} = \frac{1}{K} Res_{(n_1=\sqrt{2},\ \theta_i=\frac{\pi}{4})} \left[\frac{2}{(k_{1z}^2 + K^2) k_{1z} K} \left(\frac{k_1}{v_1} K^2 + \frac{k_2}{c} k_{1z}^2 \right) \right] .$$

Therefore the expression (2) is the trivial consequence of the formula (1).

Superluminal photon tunneling arises the problem of Einstein causality. To elucidate this problem we proceed to the analysis of evanescent-wave propagation. According to [2], the evanescent-wave wavenumber K satisfies the equation

$$k_{1x}^2 - K^2 - k_2^2 = 0 \ .$$

This equation is invariant under the group $SO(1,2)$, which is the subgroup of the group $SO(2,2)$. The group $SO(2,2)$ differs from the Lorentz group $SO(3,1)$. Therefore evanescent-wave propagation is incompatible with Einstein causality.

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References

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